

SUMMARY

Measurement of the strength and direction of magnetic fields in coronal plasmas is arguably the most important observable required for advances in our understanding of the emergence of magnetic flux into the solar atmosphere and the processes responsible for the production of solar activity, coronal heating and coronal dynamics. The COronal Solar Magnetism Observatory (COSMO) is a proposed ground-based suite of instruments designed to routinely study coronal magnetic fields and their environment. The core of the facility includes a meter-class coronagraph with instrumentation dedicated to measuring the coronal magnetic field using the polarization of forbidden emission lines in the infrared. Supporting instruments focus on prominence magnetometry, the evolution of the electron scattered corona (K-corona), and chromospheric imaging. This new facility will be operated by the High Altitude Observatory of the National Center for Atmospheric Research (HAO/NCAR) in collaboration with the University of Hawaii and the University of Michigan. It will replace the current NCAR Mauna Loa Solar Observatory which has been collecting synoptic coronal data for over 40 years in support of the solar and heliospheric community (<http://mlsso.hao.ucar.edu>). COSMO will enhance the value of existing and new observations on the ground (SOLIS, ATST, and FASR) and in space (SOHO, TRACE, GOES, SOLAR-B, STEREO, SDO) by providing unique and crucial observations of the global coronal magnetic field and its evolution.

BREAKTHROUGH SCIENCE

What are the relationships between photospheric and coronal magnetic fields? How does photospheric forcing impact coronal energy balance and dynamics?

Forcing of the corona by photospheric flux emergence and motions can be addressed with COSMO by examining large-scale, long-lived coronal structures associated with surface field advection and differential rotation. Direct comparisons can be made of photospheric vector magnetic field measurements around filaments with magnetic field observations from within the filaments by COSMO.

What kinds of magnetic configurations lead to the launch and acceleration of coronal mass ejections?

Simple inspection of the morphology of the magnetic fields in force-free vs. potential fields (see figure below) shows that the polarization signatures will be very different and detectable by COSMO. COSMO will also provide the highest temporal resolution white light images of CMEs in the very low corona (down to 1.05 solar radii).

What is the nature of the changes in coronal magnetic structure that accompany the 11-year solar cycle? Do CMEs indeed remove accumulated magnetic helicity?

COSMO will provide daily observations (from 17 UT to 02:30 UT) of the coronal magnetic field down to 1 Gauss over a 360 degree field-of-view and will be operated 365 days per year, weather permitting.

How are prominences formed, how do they evolve, and how are they related dynamically to CMEs?

Vector magnetic field observations in prominences are scarce. COSMO will provide routine observations of prominence (limb) and filament (disk) magnetic fields along with prominence flows and constraints on prominence densities that can be used to determine the structure and dynamics of prominences and their role in CME formation.

How and where are particles accelerated to high energies? Where are CME-associated shocks formed in the corona and what is their role in the production of solar energetic particle events?

Recent observations suggest that at least some shocks responsible for SEP events form very low (below 2.5 R_☉) in the solar corona. COSMO will provide information on changes in the magnetic structure of the corona over time scales of minutes, which can be used to detect compressions and distortions in the field.

What is the role of magnetic reconnection and flares in CME formation? How does the magnetic field change around flare sites?

COSMO will provide the first routine measurements of coronal magnetic fields in and around flares and CMEs as seen over the solar limb. In addition, COSMO will provide high time cadence (seconds) observations of both CMEs in white light and flares in optical and infrared (He-I) wavelengths.

PROPOSED INSTRUMENTS

A coronal magnetometer devoted to obtaining the highest quality polarimetric data of forbidden lines in the corona. Based on Judge et al. 2001 the optimal lines are Fe XIII 1074.7 and 1079.8 nm. This will consist of a new coronagraph with a large field of view, a filter instrument and a spectrograph. It would operate as a "light bucket" far from the diffraction limit, and would be placed at the best possible coronal site to reduce unwanted scattering and absorption that are detrimental to such measurements.

A prominence magnetometer devoted primarily to measurements of lines of helium (D3, 1083 nm) and perhaps H- α . A spectrograph is the instrument of choice given the narrow lines and the need for detailed spectral information in "inverting" the data.

A white-light polarized-brightness (pB) coronagraph, effectively to replace the Mauna Loa IV system by a modern, large array-based detector system capable of improving the signal-to-noise and temporal resolution by an order of magnitude while at the same time providing higher spatial resolution. Such measurements are needed to provide observations of CME formation and early acceleration. This coronagraph will provide the "third eye" for STEREO and the only white light observations of the low corona along the Earth-Sun line.

A chromospheric imager devoted to recording a significant fraction of geo-effective CME events on the solar disk via the disruption of the prominences seen on the disk (filaments) in lines of H and He-I. The instrumentation would include the ability to determine high resolution line-of-sight Doppler shifts.

SCIENCE OBJECTIVES AND INSTRUMENT REQUIREMENTS

Science Objective	Goal	Key prediction	Requirements			Other
			Field	Spatial	Temporal	
Corona photosphere connections	Model validations	Coronal field is force free, are linear approximations valid, potential fields?	1-5 G	10 arcsec	30 min	Large FOV
CME initiation	Resolve and distinguish breakout from flux rope model.	1) Magnetic twist before eruption 2) Magnetic topology of heliosphere surrounding CME	1-5 G	10 arcsec	5 min for field, 15 sec for pB, H- α , HeI	Need large FOV to see enough CMEs
Solar cycle dependence of the global corona	Measure changes in magnetic field accompanying the sunspot cycle and flux reversal	Coronal magnetic field plays an active role in shedding helicity to enable the sunspot cycle to occur.	1-5 G	5-10 arcsec	30 min	Large FOV, small pixels to determine constraints on helicity
Prominences	Resolve magnetic topology	1) Coiled magnetic field 2) Importance of mass for overall configuration and magnetic energy	5 G	2 arcsec	5 min for field, 30 sec for pB, H- α , HeI	Large FOV, velocity
Particle acceleration	Shock detection	Shock occurrence and strength coincides with particle events in the heliosphere.	1-5 G	5 arcsec	5 min for field, 15 sec for pB, H- α , HeI	Large FOV for shock detection
Reconnection and Flares	Quantify role of magnetic reconnection and Flare/CME connection	1) Test breakout, tether-cutting and flux rope models of CME. 2) Flares occur in sheared field sites	1-5 G	5 arcsec	5 min for field, 30 sec for pB, H- α , HeI	Large FOV to view entire CME

TECHNOLOGY DEMONSTRATION

Much progress has been made recently in the application of the Zeeman effect and scattering polarization technique. Figure 1 shows recent measurements (Lin et al. 2004) of circular polarization of the Fe XIII coronal emission line at 1074.7 nm. The observations were obtained with a fiber-fed spectrograph, the Optical Fiberbundle Imaging Spectropolarimeter (OFIS), behind the 46-cm aperture Solar-C coronagraph (Kuhn, et al. 2003) on Haleakala, Hawaii. The fibers subtended 20 arcseconds and the observation required 70 minutes of integration time. Notably, the errors on the line-of-sight component of the magnetic field are less than 1 G. The success of this experiment compared to the early work of Harvey (1969) is due in large part to the use of an infrared emission line which has greater sensitivity than the green coronal line at 530.3 nm employed by Harvey. These infrared observations have been enabled by the recent availability of high quantum efficiency, low-noise infrared array detectors. The precision on the magnetic field achieved with this instrument is sufficient to address many of the science goals; however, the 20 arcsecond spatial sampling and the 70 minute temporal sampling are not sufficient. More photons are required to achieve the requisite noise levels at scientifically interesting spatial and temporal scales. This can only be accomplished with a larger aperture coronagraph.

Another application of this technique is illustrated in Figure 2, which shows coronal properties measured by the HAO/NCAR Coronal Multi-channel Polarimeter (COMP) instrument obtained by Tomczyk and co-workers in April of 2005 on the 20-cm aperture OneShot coronagraph at NSO's Sacramento Peak Observatory in New Mexico. The COMP is a filter-based polarimeter also observing the Fe XIII emission line at 1074.7 nm. These observations have a spatial sampling of 4.5 arcseconds per pixel and required 30 minutes of integration time. The field strength measurements shown here are significantly worse than those shown in the previous figure due to smaller coronagraph aperture, shorter integration time and smaller pixel size. This instrument was also enabled by recent advances in infrared detector technology.

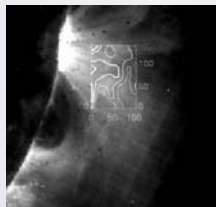


Figure 1. Coronal line-of-sight magnetogram obtained by OFIS overlaid on the IFT FeXIII 284 A image. The contours are 5G, 3G, and 1G.

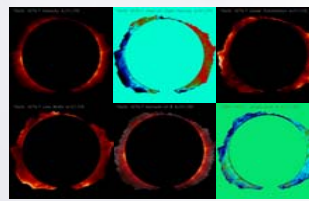


Figure 2. Clockwise from top left: the intensity, velocity, degree of linear polarization, line-of-sight magnetic field, field azimuth and line-width as observed by the CoMP instrument on 4/21/05.

ADVANCES IN INTERPRETATION TOOLS

To prepare for the exploitation of these new observations, we have started developing tools and techniques for comparing forward models of coronal magnetic fields with observations from COMP and Solar-C, as well as anticipated observations (Judge et al. 2006). Figure 3 shows a simulation of an axisymmetric equatorial current sheet embedded in the Sun's corona as it would be observed by the Fe XIII emission line at 1074.7 nm. The current sheet is derived from the analytical model of Low, Fong and Fan (2003). The plasma is optically thin and has been integrated along the line of sight. The plasma is hydrostatically distributed at 1.6 MK, and spherically symmetric. The strength of the linear and circular polarization is shown for two cases; the top two panels are for a current sheet with sufficient magnetic free energy to launch a CME while the bottom two panels show the case of a weaker current sheet with insufficient energy for CME launch. Both cases have an identical value of the radial component of the magnetic field at the solar surface; however, the polarization signatures are extremely different for the two cases. This example illustrates the sensitivity of measurements of the polarization of coronal emission lines to the degree of magnetic free energy. These differences in linear and circular polarization signals will be measurable by COSMO over scientifically interesting spatial and temporal scales.

These theoretical preparations will lay the groundwork for the facility proposed here and allow the community to fully and rapidly exploit the potential of these new observations.

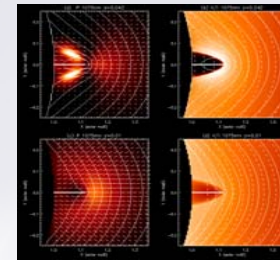


Figure 3. This figure shows the sensitivity of the Stokes parameters in the Fe XIII line at 1074.7 nm to the presence and strength of an axisymmetric equatorial current sheet in the Sun's corona. These synthetic images have 4x4 arcsecond resolution. Panel (a): Magnitude (image density from 0 to 5 erg cm⁻² s⁻¹ arc⁻¹) and magnitude and direction of linear polarization P (short lines) computed for a relatively strong current sheet with sufficient magnetic free energy to launch a CME [33]. The solid lines are magnetic field lines. Panel (b): Stokes V (relative circular polarization between +/-10⁻³) for the same case as seen from the Earth with the Sun's S. pole inclined towards us by 7 degrees. Dashed lines show a global dipolar magnetic field which has the same radial magnetic field at the surface as the current carrying case. Panels (c) and (d) show the same calculations for a weaker current sheet with insufficient energy for CME launch. Note the very different polarization signatures of the two cases.

COSMO AND THE COMMUNITY

Due to its scientific relevance and its expected far-reaching impact, COSMO will pursue a new paradigm of community involvement and innovation. The targeted community is focused on, but not limited to, US universities pursuing solar and heliospheric research. The university community will be an intrinsic part of the entire COSMO effort, and will be represented from the beginning by two universities (University of Michigan, University of Hawaii) in the prime COSMO construction team. Furthermore, a COSMO user committee (USCOMM) has been established, which will advise the COSMO team, and will become a crucial link between user needs and the new facility. The interactions between COSMO and the national and international community broadly fall into four categories which are:

Involve students in all phases of the COSMO project - Undergraduate and Master students will be involved through the participating universities, and through dedicated HAO/NCAR summer programs. A specific opportunity will be made available for COSMO PhD fellows, selected through a National competition, either run through the NSF or through the USCOMM. These fellowships will involve hands-on experiences with COSMO that can either focus on technology development or data analysis from this facility.

Through an open data policy, provide all key COSMO observational data to the community - All relevant synoptic and campaign data, as defined by USCOMM, will be made available to the public. The direct community involvement is considered crucial, because it allows adaptations and community input.

Provide COSMO facility in a campaign mode - Through proposed campaigns, certain science topics will be pursued which require coordination between the COSMO instruments, or between COSMO and other observational tools on the ground or in space. The selection of the COSMO campaigns will be done by USCOMM and care will be taken that these campaigns allow COSMO to be consistent with its mission as a synoptic instrument for key systems.

Provide parts of the COSMO facility as a technology test bed for breakthrough technology development - It is the goal of the COSMO facility to provide easy access to test technology development efforts typically funded through independent investigations. The multi-instrument nature of the COSMO facility enables this interaction without jeopardizing the primary science.

In summary, the four-pronged strategy of enhanced community interaction will be unique and take full advantage of COSMO as a ground-based facility. There is an important second benefit: COSMO, as proposed, is an optimized observation system following modern observation technologies and with knowledgeable staff. But paradigm-altering science progress and technology will motivate refinements in COSMO's observational strategy. It is the purpose of COSMO's management plan to incorporate innovations and accommodate changes to meet future community needs. Only then will we be sure that COSMO will deliver on its scientific promise, for decades to come.